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HYBRID PASSIVE TRACKING ALGORITHMS. EXECUTIVE SUMMARY.(U)
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# HYBRID PASSIVE TRACKING ALGORITHMS

## EXECUTIVE SUMMARY

Submitted to:

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## 1.0 INTRODUCTION

For the past several years Tracor has been conducting research on the performance and utility of a batch algorithm, used for underwater tracking with passive sonobuoys, called the Maximum Likelihood Procedure (MLP). Testing experience, using both real and simulated data, with the MLP indicated the following:

(1) The MLP is self-initializing. That is, good initial estimates of the state vector can be generated from the data. There is no need to supply an accurate initial guess.

(2) The MLP requires several different motion models to characterize possible submarine maneuvers. Model selection can become a problem in terms of time and appropriateness.

(3) Because the MLP processes data in a batch, extremely accurate estimates of the state vector can be obtained when the proper motion model has been selected. However, serious loss of track can occur when the model currently being used no longer becomes valid but the selection process has not yet picked a new one.

(4) The algorithm possesses moderate to substantial computer time requirements, based upon the complexity of the track

being attempted, and moderate storage requirements.

To provide a means of comparison with the MLP and also in an attempt to gain insight into the applicability of sequential algorithms to underwater tracking, Tracor, in conjunction with Dr. Byron Tapley of the University of Texas, designed and implemented a sequential tracking algorithm based on the extended Kalman filter. While testing this algorithm several things became clear:

(1) The sequential had smaller core storage and execution time requirements than the MLP.

(2) Tracking accuracy was as good or better than the MLP.

(3) The sequential algorithm was highly susceptible to initialization errors, requiring a fairly close initial state vector estimate in order to produce a good track.

(4) The sequential model could be implemented with a single stochastic motion model. This eliminated the need for the model selection process and also allowed some "slack" in estimating the tracking parameters.

## 2.0 HYBRID RESEARCH EFFORT AND PROGRAM OBJECTIVES

After testing of the MLP and sequential algorithms revealed their complementary strengths, it was decided that a combination of the two approaches, or a hybrid algorithm, should be developed. It was hoped that the MLP could initialize the tracking procedure for the sequential algorithm and also provide reinitialization should the sequential lose track. A preliminary version of the hybrid was created using the MLP and sequential algorithms and early tests showed potential. However, several problems remained. Among them were:

(1) The MLP was too cumbersome to use efficiently as an initializer; a more efficient batch procedure was needed.

(2) The sequential algorithm's numerical properties needed to be improved.

(3) Improvement and refinement of the switching rules for moving from batch to sequential and sequential to batch were needed.

(4) Several generalizing program changes needed to be introduced.

Thus, the primary objectives of this contract were to: implement a simpler, faster batch initializing procedure; implement a numerically more stable sequential algorithm; devise more appropriate switching rules for going from batch to sequential and vice versa; and to streamline

and generalize the program. These objectives were met in the following manner:

(1) A streamlined MLP algorithm using only one motion model (constant linear acceleration) was developed and implemented. It was felt that, if appropriate switching rules could be developed, this model would be able to produce effective initial estimates over fairly short time intervals, and that a change to the sequential algorithm could be performed before model lack of fit became significant.

(2) A numerically stable, computationally efficient sequential algorithm was implemented using the $U^TDU$ square root filter formulation.

(3) A successful batch to sequential switching rule was devised using a non-linear regression test for parameter significance developed by Gallant [1]. Additionally, a successful sequential to batch procedure was developed by testing measurement model residuals for trends using standard linear regression techniques.

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[1] Gallant, A.R., "The Power of the Likelihood Ratio Test of Location in Nonlinear Regression Models," J. Am. Stat. Assoc., Vol. 70, No. 349, pp. 198-203, March, 1975.

## 3.0 ANALYSIS SUMMARY

Once the improved hybrid algorithm had been constructed and tested, a second algorithm was constructed which replaced the batch initializer with an iterated sequential initializer. Four tracking scenarios were then constructed, each replicated 25 times as a series of Monte Carlo runs. The scenarios were intended to contrast the relative performance of the algorithms over a range of tracking difficulties. Each algorithm was then run over the four scenarios and they were compared using the following criteria:

(1) Average distance error throughout the track.

(2) Percent holding time throughout the track, that is, percent of total scenario time that estimated target position is within 500 meters of true position.

(3) Predictive ability, i.e., assuming the target stays on track, how well can the algorithm predict target position after the end of data?

(4) Average CPU time required to process one scenario.

## 4.0 CONCLUSION

Based on the results of the Monte Carlo simulations it is evident that the hybrid algorithm is superior to both the MLP and iterated sequential algorithms. In every scenario examined the hybrid not only had the lowest average execution time (often by a factor of three or four), but also the lowest average distance error. In addition, the hybrid usually had tighter sigma-bounds about the distance error than either of the other two algorithms.

Comparisons between the iterated sequential and the MLP are somewhat more difficult to make. For all scenarios the iterated sequential executed considerably faster than the MLP. Also, once the iterated sequential had enough points to provide correct initialization, there appeared to be no difference between the two algorithms in terms of distance error or error variance. Thus, it is only early in a given initialization or reinitialization phase that the iterated sequential does not perform as well as the MLP. The overall conclusion is that, all things considered, the iterated sequential and the MLP algorithms are roughly equal.

## 5.0 RECOMMENDATIONS

The recommendations arising from this study fall into two natural groups, those dealing with the improvement or modification of one of the algorithms and those dealing with analysis of the capabilities and robustness of each algorithm. Recommendations for algorithm improvement or modification include:

(1) Dealing With Outliers. At present, neither the hybrid nor the sequential has an effective method for dealing with bad data points or a bad data stream from one particular sensor. There are several schemes for dealing with outliers (such as the procedure used in the MLP) and they should be investigated for use in the hybrid and sequential algorithms.

(2) Optimize Sequential Initializer. Software is being developed which will allow the sequential starter to optimize a given state vector estimate with respect to the true measurement models and not some linear approximation. This should be completed and the new optimal initializer installed.

(3) Add Higher Order Terms. For the hybrid algorithm, the optimization procedure used in the batch initializer was equivalent, in result, to using higher order

terms in the measurement model approximations. However, in the sequential portion of the algorithm these optimization procedures were not implemented in order to minimize execution time. By using higher order terms in the measurement models employed by the sequential filter, it may be possible to increase tracking accuracy without significantly raising scenario execution time.

Recommendations for determining and comparing the robustness of each algorithm include:

(1) Tests on Real Data. Using the non-gaussian, simulated data of this study, all three tracking algorithms did well. However, the true test of any algorithm's capabilities is its performance on actual sea data. Once the modifications proposed above have been completed, all three algorithms should be tested on real data taken from several scenarios.

(2) Effects of Data Quality and Data Rate. During testing of the hybrid, scenarios with different data rates and qualities were produced and tested. Indications were that data rate was more a factor in determining good tracking accuracy than was data quality. Using analysis of variance/response surface techniques, it may be possible to determine the

relative importance of data rate, data quality, and buoy number and to identify certain optimal conditions.

(3) Effect of Buoy Drift. All scenarios analyzed in this study assumed constant buoy positions throughout the scenario. Of course, in actual practice this is not the case and the best algorithm is that one which is most efficient in the face of buoy position uncertainty. The necessary software is in place in the hybrid and sequential to generate buoy position estimates, however, there would be a certain amount of programming involved in generating the simulated measurements.

(4) Examine Other Data Types. For this study the only data types used for each scenario were frequency and bearing. However, there are other data measurements which can be used for tracking, such as range, time difference of arrival, Doppler ratio, and Doppler difference.

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